nisse der Rechenkünstler, by D. E. Smith; Study's Konforme Abbildung einfach-zusammenhängender Bereiche, by Arnold Emch; "Notes;" and "New Publications."

THE July number of the *Bulletin* contains: Report of the April meeting of the society in New York, by F. N. Cole; Report of the twenty-fifth regular meeting of the San Francisco section, by Thomas Buck; "The ratio of the arc to the chord of an analytic curve need not approach unity," by Edward Kasner; "A Mersenne prime," by R. E. Powers; Review of Osgood's Lehrbuch der Funktionentheorie, by E. B. Van Vleck; "Notes;" "New Publications;" Twenty-third annual list of published papers; and Index of Volume 20.

THE October number (Vol. 21, No. 1) of the *Bulletin* contains: "On a small variation which renders a linear differential system incompatible," by Maxime Bôcher; "The smallest characteristic numbers in a certain exceptional case," by Maxime Bôcher; "On approximation by trigonometric sums," by T. H. Gronwall; "Note on the roots of algebraic equations," by R. D. Carmichael and T. E. Mason; "Remarks on functional equations," by A. R. Schweitzer; "Shorter Notices;" Hadamard's Leçons sur le Calcul des Variations, Tome premier, by E. R. Hedrick; Boutroux's Principes de l'Analyse mathématique, Tome premier, by J. B. Shaw; Blumenthal's Principes de la Théorie des Fonctions entières d'Ordre infini, by G. D. Birkhoff; Riesz's Systèmes d'Equations linéaires à une Infinité d'Inconnues, Bowley's General Course of Pure Mathematics from Indices to Solid Analytic Geometry, and Fabry's Démonstration du Théorème de Fermat, by R. D. Carmichael; Silberstein's Vectorial Mechanics, by E. B. Wilson; "Notes;" and "New Publications."

SPECIAL ARTICLES

VITALITY AND INJURY AS QUANTITATIVE CONCEPTIONS

ALTHOUGH a fundamental conception of physiology, the idea of vitality has not been very precisely formulated. This is not only unfortunate from a theoretical standpoint, but it also has practical disadvantages. The physiologist often finds that the validity of his conclusions depends on selecting material of normal validity for his experiments. When he examines organisms for this purpose he is too apt to find that all the tests of vitality which he employs are uncertain or that at best they lack the precision necessary for quantitative work.

An accurate method of measuring vitality seems therefore to be needed not only for more precise formulation of the conception itself, but also for practical purposes.

The investigations of the writer lead to the conclusion that the vitality of a tissue is so dependent on the maintenance of its normal permeability that we may employ the permeability of protoplasm as a sensitive and reliable indicator of its vitality. We may therefore obtain an accurate measure of the vitality of a tissue by carefully measuring its permeability.

This may be accomplished by determining the electrical resistance of living tissues. This method is rapid and convenient for practical use. It may be applied to pieces of detached tissue or to the intact organism.

The writer began the use of this method by cutting disks from the fronds of the marine alga, *Laminaria saccharina*, and measuring their electrical resistance in a manner which has already been described.[1] Subsequently it was found possible to measure the resistance of intact fronds both of *Laminaria* and of other plants by methods which will be described in detail in a future publication.

As the result of his experience with this method the writer concludes that it is often very difficult to judge of the condition of an organism by its appearance. The tissues on which experiments have been made were found to be capable of losing much of their vitality without betraying it in any way by their appearance. (This was particularly the case with eel grass, *Zostera*, which retained its normal green color and appearance for some days after

[1] SCIENCE, N. S., 35: 112, 1912.

electrical measurements showed it to be dead.) On the other hand, material of doubtful appearance often turned out to be much better than that which looked to be in sound condition. It seems quite possible that this will be found to be the case with other organisms when quantitative tests are applied.

Material collected in a restricted locality and examined as soon as taken from the ocean gave a very uniform resistance. The same number of disks were used in each experiment, and as the disks were packed together like a roll of coins the length of the roll gave an accurate measure of the average thickness of the disks. To make the comparison as accurate as possible disks of the same average thickness were used in all the experiments. Under these circumstances the resistance at 18° C. did not vary much from 1,300 ohms. For example, in a series of determinations of ten different lots of tissue the highest reading was 1,320 ohms and the lowest 1,285 ohms. These lots of tissue were allowed to remain in the laboratory under different conditions. Some were placed in running salt water while others were allowed to stand in still salt water in pans of various sizes. Some of these were placed in direct sunlight (where the temperature rose to an injurious point) while others were kept in a cool place and sheltered from direct sunlight. At the end of twenty-four hours there was no difference in the appearance of these lots, but their electrical resistance varied from 400 ohms to 1,320 ohms. All were then placed side by side in the same dish. Those with the lowest resistance were the first to die, as was shown by the fact that their resistance fell to the death point (about 330 ohms) and became stationary. The others died in the order indicated by their electrical resistance.

Determinations of the resistance made it evident that in no case did visible signs of death make their appearance until twenty-four hours after death occurred, and subsequent experiments showed that in some cases (especially at low temperatures and in the presence of certain reagents) they may not appear until several days after death.

It was found that material from one locality showed a low resistance and subsequent examination showed that it was contaminated by fresh-water sewage. The appearance of the plants was not such as to lead to their rejection for experimental purposes. They did not survive as long in the laboratory as plants of normal resistance taken from the other localities.

It may be taken for granted that vitality, whatever else it may signify, means ability to resist unfavorable influences. When organisms which are of the same kind, and similar in age, size and general characters, are placed under the same unfavorable conditions, the one which lives longest may be said to have the greatest vitality;[2] the one which lives next longest may be rated second in this respect, and so on. Determination of the electrical resistance of these individuals enables us to predict at the outset which will live longest, which next longest, and so on through the entire group.

Moreover, we find that all influences which impair vitality lower the electrical resistance. It is therefore obvious that determinations of electrical resistance afford a means of measuring vitality and in the course of an extensive series of experiments it has been found that this method may be relied upon to give accurate results.[3]

[2] It might be expected that this individual would also excel in other respects. A discussion of these is unnecessary from our present standpoint: in so far as they can be quantitatively treated they form proper material for a supplementary investigation.

[3] It is evident that the most accurate comparisons will be secured when the tissues or organisms are closely similar in structure, for variations in structure may cause variations in electrical resistance. To compare tissues or organisms which differ in structure (or which for any other reason differ in the absolute number of ohms which expresses their normal resistance) we may use the fall of electrical resistance in a given time under unfavorable conditions (expressed as percentage of the normal net resistance, as suggested below in the discussion of injury) or we may use the speed of recovery from injury of a definite degree. The fall of resistance need not proceed beyond the point at which complete recovery is pos-

The fact that determinations of electrical resistance afford an accurate measure of vitality enables us to attach the same sort of quantitative significance to normal vitality as we attach to normal size or to normal weight. For this purpose we may construct a variation curve and determine the mode in the usual way.

There is no reason to suppose that the vitality of an individual organism is constant any more than its weight is. There is probably some fluctuation which usually passes unperceived unless a quantitative method of detecting it exists. The writer finds that some substances which are normally produced in the organism alter its electrical resistance. Certain reagents may produce marked alteration of resistance without permanent injury. For example, tissue of *Laminaria* having a resistance of 1,020 ohms was placed in NaCl .52 M, which had the same conductivity as the sea water; in the course of a few minutes the resistance fell to 890 ohms, but on being replaced in sea water it rose in the course of a few minutes to the normal amount, where it remained. This was repeated on the same piece of tissue for several days without any sign of permanent injury.[4]

It is therefore evident that considerable fluctuations in vitality may occur without leaving any permanent record.

The determination of electrical resistance makes possible a quantitative treatment of injury. It is obvious that this is as important as a quantitative treatment of vitality. The degree of injury may be defined as the amount[5] by which the resistance falls below the normal net resistance. Temporary injury may be defined as that from which the organism fully recovers, while permanent injury may be defined as that which is not followed by complete restoration of the normal resistance.[6]

From a theoretical standpoint it may be desirable to use in place of the resistance its reciprocal, the conductance.

We may now turn our attention to the significance of this method of measuring vitality and injury. Since the conductivity of the tissue is a measure of the permeability of the protoplasm to ions it is evident that in this method the permeability of the protoplasm is used as an indicator of its vitality. This is in accord with the results of long experience. In doubtful cases it has been customary to determine whether a cell was alive or dead by its ability to contract in a plasmolyzing solution or to resist staining by certain dyes. The diffusion of certain substances out of the cell has long been recognized as a sign of death. All of these are tests of permeability. These criteria have been successfully employed in cases where there was nothing in the appearance of the cell to indicate whether it was alive or dead.

The writer has found that the method of plasmolysis may be utilized to distinguish not only between living and dead cells, but also between cells of normal vitality and those in which vitality has been impaired by certain reagents. In these experiments the reagent was not allowed to act long enough to produce permanent injury.

Lack of space renders it impossible to go into the details of these investigations, but attention may be called to experiments already published which may be interpreted from this point of view.[7] These experiments show that cells recover more quickly from plasmolysis (and consequently have greater permeability) in solutions in which their vitality is impaired.

For example it was found that in sea water suitably diluted a cell of *Spirogyra* when

sible and after recovery the material may be used for experimental purposes. In this way individuals of different species or unlike tissues of the same individual may be compared with respect to vitality. From a theoretical standpoint it may be desirable to use in place of the resistance its reciprocal, the conductance.

[4] SCIENCE, N. S., 36, 350, 1912.

[5] This is best expressed as percentage of the normal net resistance; the net resistance is found by subtracting the resistance of the apparatus.

[6] The term injury as used by the writer in previous papers is synonymous with the term permanent injury as here defined.

[7] SCIENCE, N. S., 34, 187, 1911.

plasmolyzed to a moderate degree[8] recovered in about twenty-four hours. The *Spirogyra* lives and maintains its normal permeability indefinitely in such dilute sea water.

When placed in a solution of pure NaCl .4 M the vitality of the cell is rapidly impaired and it dies in the course of two or three hours.[9] If such a cell be plasmolyzed by .4 M NaCl to a moderate degree[8] it recovers in the course of half an hour. Since the permeability is inversely proportional to the time of recovery, it is evident that the NaCl impairs the vitality of the cell and at the same time increases its permeability.[10] The two processes go hand in hand. The permeability continues to increase until death occurs, when the cell becomes completely permeable.

These experiments were repeated with a variety of reagents and were afterward confirmed in every detail by the method of determining electrical resistance.

As the result of these and other experiments we may say that the permeability is greatly affected by changes in the composition of the salt solution in which the cell is placed. Normal permeability is best preserved in solutions in which the proportions of salts are approximately the same as in sea water and normal vitality is also maintained longest in these solutions. In general we find that vitality and permeability are affected in exactly the same way by various kinds of electrolytes.

This principle may be applied much more generally. The writer finds that all substances (whether organic or inorganic) and all agents (such as excessive light, heat, electric shock, mechanical shock, partial drying, lack of oxygen, etc.) which alter the normal permeability of the protoplasm shorten the life of the organism. This is equally true whether the alteration consists in an increase of permeability, or in a decrease of permeability (followed by an increase) as is the case when certain reagents (such as $CaCl_2$) are applied.[1] This is a very striking fact and its significance in the present connection seems to be clear and unmistakable. It shows in the most convincing manner that permeability is a delicate and accurate indicator of vitality.

We are unable to say why there is such an intimate connection between vitality and permeability. It is evident that permeability may control metabolism by regulating the osmosis of various substances, and conversely that metabolism may affect permeability. What is needed is not more speculation in this direction, but a careful analysis of the factors which control permeability. If we are successful in determining what these factors are we may hope to arrive at a more satisfactory formulation, in physico-chemical terms, of our conception of vitality as well as of that of injury.

W. J. V. OSTERHOUT
LABORATORY OF PLANT PHYSIOLOGY,
HARVARD UNIVERSITY

[8] This degree is a definite one. It was usually chosen as the condition in which the protoplast just touched the end walls.

[9] This applies only to the species of *Spirogyra* used in these experiments: some species may be more resistant while others are much more sensitive and are killed in less than ten minutes.

[10] In other solutions in which vitality is more rapidly impaired the recovery from plasmolysis is also more rapid and we must conclude that the permeability is proportionately increased.

SOIL ACIDITY AND METHODS FOR ITS DETECTION

THE so-called "acid" soils are peculiar in that a solution obtained by shaking such soils with water will be found, except in rare cases, to be absolutely neutral toward litmus paper. However, if the test paper be brought into direct contact with the soil particles themselves, a very sharp acid reaction will be obtained. These acid soils possess another peculiar property in that if shaken with a solution of some neutral salt such as sodium chloride, an appreciable amount of a soluble acid will be found to be set free.

Two theories have been advanced to explain these properties. The older and perhaps still the most generally accepted theory is the humic acid theory. This theory assumes that there are present in the acid soils, as the result of the decomposition of animal and vegetable matter, some very insoluble organic acids called humic acids. These are supposed to be definite